Correlation of Dokusawa and Kitahara Tephras in the Central Part of Northeast Japan : EPMA Analyses of Heavy in the World Megalopolis

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Correlation of Dokusawa and Kitahara Tephras in the Central Part of Northeast Japan
—— EPMA Analyses of Heavy Minerals ——

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Abstract Dokusawa tephra (Dks) and Kitahara tephra (Kth) are Late Pleistocene tephra layers containing biotite and cummingtonite characteristically. Dks is distributed on the western side of the Ou Ranges and Kth is on the eastern sides of the Ranges in the central part of Northeast Japan. Vertical variations of modal amounts and major element chemistry of minerals were examined on Dks and Kth.

Cummingtonite shows nearly constant variation in Mg-values [Mg/(Mg+Mn+Fe)]. On the contrary, Mg-values of orthopyroxene and hornblende have wide variations. Dks and Kth correlate with each other because chemical composition of cummingtonite are quite similar. Dks comprises cummingtonite, biotite, high-quartz and epidote as a whole layer. The upper part of Dks also includes orthopyroxene, clinopyroxene and hornblende. The mineral composition of Kth resembles the upper part of Dks and does not show vertical variation. These facts indicate that the upper part of Dks is distributed on both sides of the Ou Ranges.

Key words: Dokusawa tephra, Kitahara tephra, EPMA, heavy minerals, central part of Northeast Japan

1. Introduction

Dokusawa tephra (Dks: Matsu'ura, 2000) and Kitahara tephra (Kth: Soda, 1989) are Late Pleistocene tephra layers containing biotite and cummingtonite characteristically. Dks is distributed on the western side of the Ou Ranges and Kth is on the

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eastern part of the Ranges. Assemblage and chemistry of minerals in Dks and Kth are very similar (Matsu'ura, 2000) but the correlation of the two tephras has not yet been clarified. Dks and Kth are useful key horizon for Late Pleistocene chronology of sediments, landforms and artifacts in the central part of Northeast Japan. Modal abundance and major element chemistry of minerals were examined on Dks and Kth for correlation in this paper[1].

2. Petrographical features of Dks and Kth in the previous studies

2.1. Dks

Dks is greenish-gray coarse ash fall layer and it contains biotite, cummingtonite and orthopyroxene (Kitamura *et al.*, 2000 ; Matsu'ura, 2000). Nitta *et al.* (2001) reported that Dks also includes clinopyroxene, hornblende, epidote and high-quartz (Table 1).

Mg-value [$Mg/(Mg+Mn+Fe)$] of cummingtonite is reported as 0.568-0.571 (Matsu'ura, 2000), 0.574-0.577[2] (Kitamura *et al.*, 2000), 0.582-0.591 (Nitta *et al.*, 2001) respectively (Table 1).

Eruptive age of Dks is slightly later than 100 ka (Kamata *et al.*, 1993 ; Matsu'ura, 2000) because Dks is above Sambe-Kisuki tephra (SK : Tsukui and Sakuyama, 1981 ; Toyokura *et al.*, 1991 ; Machida and Arai, 1992).

Maximum thickness of Dks is 100 cm at southwest of loc. 1. A source vent of Dks is presumably situated in the area of Hijiori caldera-Mt. Gassan-Mt. Hayama triangle or its southwest (Fig. 1). But the source volcano of Dks has not yet been found.

2.2. Kth

Kth is greenish-gray coarse ash fall layer and it contains biotite, cummingtonite and hornblende (Soda, 1989). Kanisawa *et al.* (1995) reported that Kth also includes clinopyroxene, orthopyroxene and epidote (Table 1).

Mg-value of cummingtonite is reported as 0.58-0.59 (Kanisawa *et al.*, 1995), 0.572-0.579[2] (Kitamura *et al.*, 2000), 0.582-0.594 (Nitta *et al.*, 2001) respectively (Table 1). Mg-value of orthopyroxene is reported as 0.56-0.66 (Nitta *et al.*, 2001).

Eruptive age of Kth is determined as 70.3 ka by Thermo-Luminescence dating (Ichikawa, 1988). Soda (1989) and Yagi and Soda (1989) reported that stratigraphic position of Kth is above Ontake-Pm1 tephra (On-Pm1 : Kobayashi *et al.*, 1968) and is below Aso-4 tephra (Machida *et al.*, 1985). Eruptive age of On-Pm1 and Aso-4 are determined as 84-89 ka and 90-95 ka respectively by marine isotope stratigraphy (Machida, 1999), therefore, eruptive age of Kth is given as 84-95 ka[3]. A source vent of Kth is unknown.

Table 1. Petrological features of Dokusawa and Kitahara tephras

Tephra	Reference	Heavy mineral assemblage						Qtz	Mg-value	
		Bt	Cpx	Cum	Ep	Hbl	Opx		Cum	Opx
Dokusawa (Dks)	Matsu'ura (2000)	●	–	●	–	–	●	–	0.568–0.571	–
	Kitamura *et al.* (2000)	●	–	●	–	–	–	–	0.574–0.577*	–
	Nitta *et al.* (2001)	●	●	●	●	●	●	●	0.582–0.591	0.50–0.60
Kitahara (Kth)	Soda (1989)	●	–	●	–	●	–	–	–	–
	Machida & Arai (1992)	●	–	●	–	●	●	–	–	–
	Kanisawa *et al.* (1995)	●	●	●	●	●	●	/	0.58 –0.59	–
	Kitamura *et al.* (2000)	●	–	●	–	–	●	–	0.572–0.579*	–
	Nitta *et al.* (2001)	●	●	●	●	●	●	●	0.582–0.594	0.56–0.66

Bt : Biotite, Cpx : Clinopyroxene, Cum : Cummingtonite, Ep : Epidote, Hbl : Hornblende, Opx : Orthopyroxene, Qtz : Quartz. Opaque minerals (Magnetite etc.) are not shown.
● : reported, – : not reported, / : not discussed
* : Value calculated by authors.

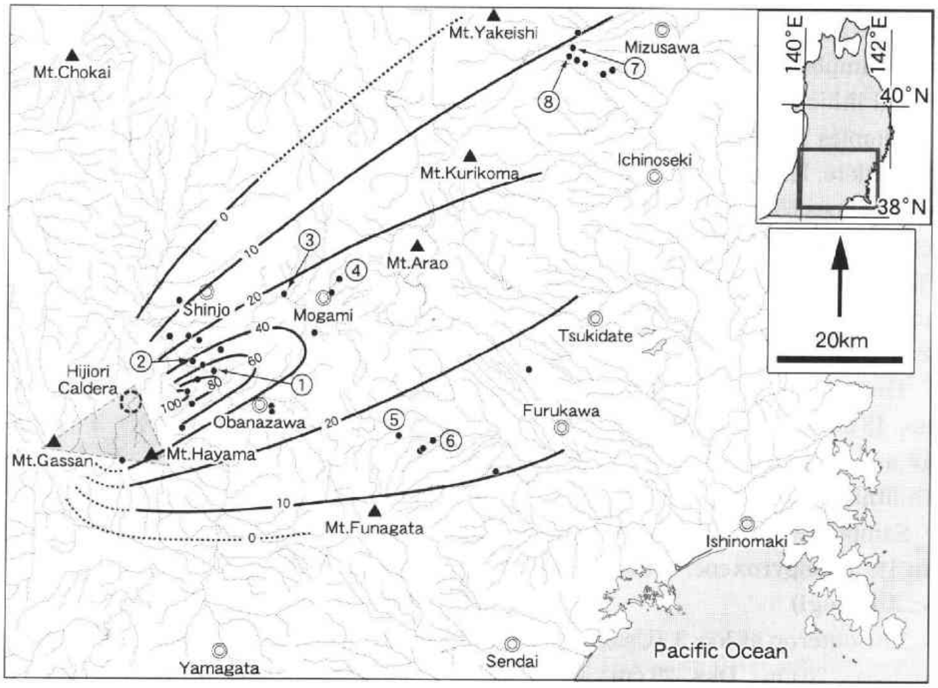

Fig. 1. Isopach of Dokusawa tephra (Dks) in the central part of Northeast Japan (in cm) After Matsu'ura (2000) and partially interpolated with new data. Dks is called as Kitahara tephra (Kth) around locs. 5–8.
①~⑧ are location numbers of outcrops.

3. Description of Dokusawa and Kitahara tephra layers

3.1. Facies, stratigraphic position and modal abundance

Facies, stratigraphic position, mineral assemblage[4] of Dks and Kth are described as follows. Dks are sampled at locs. 1-4, Kth are done at locs. 5-8. Geological columns, sampling point and modal abundance are shown in Fig. 2.

Loc. 1 (Dokusawa)

Dokusawa is the type locality of Dks described by Matsu'ura (2000). The outcrop at loc. 1 includes, in ascending order, silt, over 150 cm; loess, 10 cm; SK, 3-4 cm; loess, 10 cm; Dks, 70 cm; loess, 85 cm; Hijiori-Obanazawa tephra (H-O: Yonechi and Kikuchi, 1966; Soda, 1989), several cm as patch; humic soil.

The base of Dks is light brown clay layer[5], 2 cm thick. Above the clay layer, greenish gray ash layer (samples 1-a to 1-g in ascending order) is 17 cm thick. This layer is interstratified coarse ash and fine ash layers. Samples 1-a, 1-c, 1-e, 1-g includes coarse ash with lithic fragments (max. 4-5 mm). Samples 1-b, 1-d, 1-f includes fine ash with lithic fragments (max. 1mm). Above the ash layer, greenish gray ash layer (samples 1-h and 1-i) is 8 cm thick. Samples 1-h and 1-i are composed of coarse and fine ash with lithic fragments. Above the ash layer, greenish gray ash layer (samples 1-j to 1-r) is 40 cm thick. Samples 1-j to 1-r are composed of coarse ash and lithic fragments. This layer is dotted by pumice (>1 cm).

Samples 1-a to 1-g contains 50-90 modal % magnetite, 5-10% cummingtonite, 5-10% epidote, less than 1% clinopyroxene, orthopyroxene and hornblende. Samples 1-h and 1-i does 60% magnetite, 20% cummingtonite, 10% epidote, less than 1% clinopyroxene, orthopyroxene and hornblende. Samples 1-j to 1-r does 40-60% magnetite, 15-20% cummingtonite, 15-20% epidote, 1-7% clinopyroxene, 1% hornblende and less than 1% orthopyroxene.

Loc. 2 (Horiuchi)

The outcrop at loc. 2 (Horiuchi) includes, in ascending order, silt, over 200 cm; loess, 13 cm, with clacks; Dks, 40 cm; loess, 100 cm; humic soil. Dks is greenish gray ash layer (sample 2-a) with weak lamination. Dks is composed of coarse ash with lithic fragments.

Sample 2-a contains 65 modal % magnetite, 10% cummingtonite, 10% epidote, less than 1% clinopyroxene, orthopyroxene and hornblende.

Loc. 3 (Usugi)

The outcrop at loc. 3 (Usugi) includes, in ascending order, gravel and silt, over 200 cm; loess, 20 cm; Dks, 20 cm; loess, 50 cm; humic soil. Dks is greenish gray ash layer (samples 3-a and 3-b). Dks is composed of coarse ash with sand and lithic fragments.

Sample 3-a contains 75 modal % magnetite, 12% cummingtonite and 5% epidote,

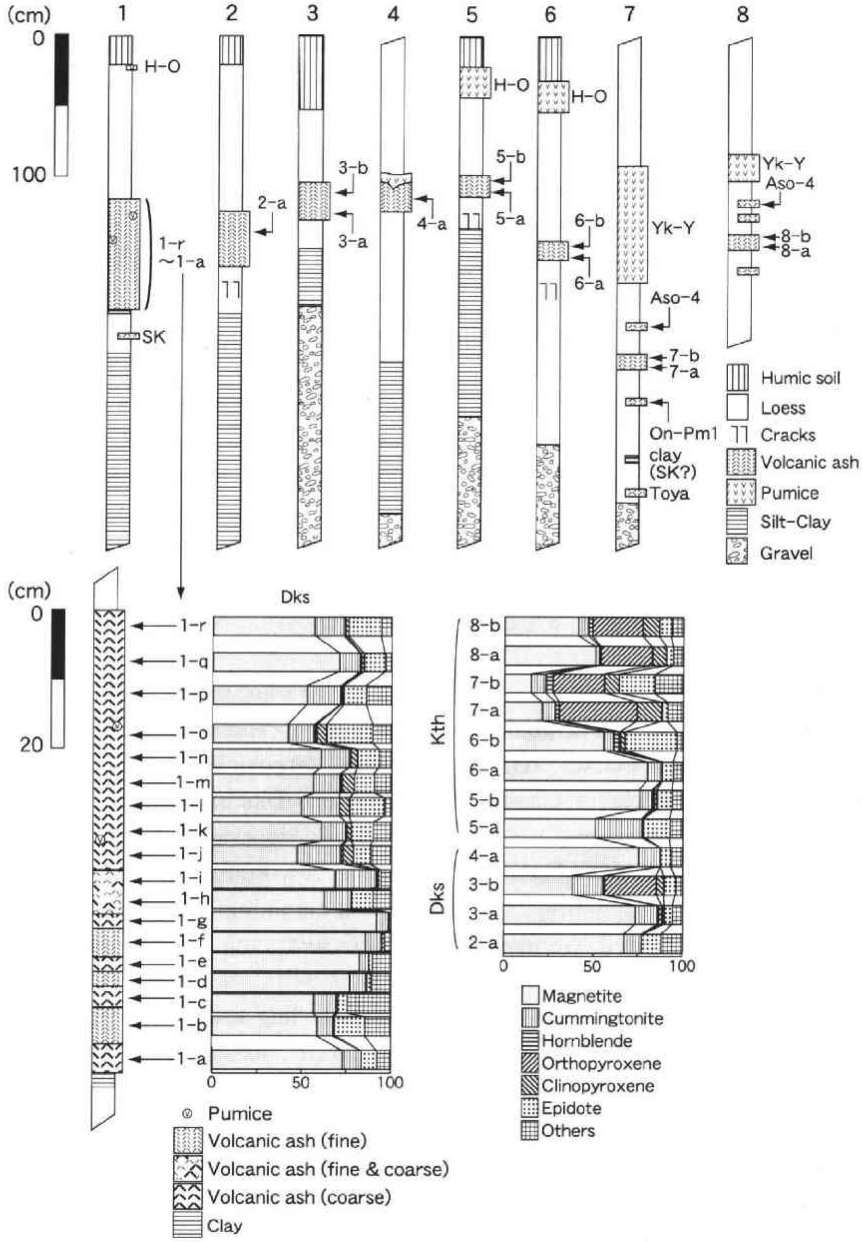

Fig. 2. Geological columns and mineral assemblages of Dokusawa (Dks) and Kitahara (Kth) tephra samples
Abbreviation of tephras
H-O: Hijiori-Obanazawa, Yk-Y: Yakeishi-Yamagata, On-Pm1: Ontake-Dai1, SK: Sambe-Kisuki.

2% orthopyroxene, 1% clinopyroxene, and 1% hornblende. Sample 3-b does 40% magnetite and 30% orthopyroxene, 17% cummingtonite, 6% epidote, 4% clinopyroxene and less than 1% hornblende. Modal abundance between sample 3-a and 3-b are quite different each other.

Loc. 4 (Maemorihara)

The outcrop at loc. 4 (Maemorihara) includes, in ascending order, gravel and silt, over 250 cm ; loess, 100 cm ; Dks, 20 cm ; secondary pumice layer, 10-20 cm ; loess, 100 cm. Dks is greenish gray ash layer (sample 4-a). Dks is composed of coarse ash with sand.

Sample 4-a contains 76 modal % magnetite, 13% cummingtonite and 6% epidote.

Loc. 5 (Mt. Yakurai)

The outcrop at loc. 5 (Mt. Yakurai) includes, in ascending order, gravel and silt, over 250 cm ; loess, 20 cm, with clacks ; Kth, 15 cm ; loess, 50 cm ; H-O, 20 cm ; humic soil. Dks is greenish gray ash layer (samples 5-a and 5-b). Dks is composed of coarse ash with sand and lithic fragments.

Sample 5-a contains 50 modal % magnetite, 25% cummingtonite and 15% epidote, less than 1% clinopyroxene, orthopyroxene and hornblende. Sample 5-b does 75% magnetite, 7% cummingtonite, 6% epidote, 2% orthopyroxene, less than 1% clinopyroxene and hornblende.

Loc. 6 (Yachibukuro)

The outcrop at loc. 6 (Yachibukuro) includes, in ascending order, gravel, over 80 cm ; oess, 140 cm, with clacks ; Kth, 13 cm ; loess, 90 cm ; H-O, 20 cm ; humic soil. Dks is greenish gray ash layer (samples 6-a and 6-b). Dks is composed of coarse ash with sand and lithic fragments.

Sample 6-a contains 80 modal % magnetite, 8% cummingtonite, 5% epidote. Sample 6-b does 55% magnetite, 28% epidote, 6% cummingtonite 3% clinopyroxene, 3% hornblende and 1% orthopyroxene.

Loc. 7 (Atago)

The outcrop at loc. 7 (Atago) includes, in ascending order, gravel, over 50 cm ; loess, 5-10 cm ; Toya (Machida *et al.*, 1987), 2.5 cm ; loess, 20 cm ; silt[6], 4 cm as patch ; loess 45 cm ; On Pm1, 4 cm ; loess, 20 cm ; Kth, 10 cm ; loess, 7 cm ; Aso-4, 3-4 cm ; loess, 30 cm ; Yakeishi-Yamagata tephra (Yk-Y : Okami and Yoshida, 1984). Dks is greenish gray ash layer (samples 7-a and 7-b). Dks is composed of coarse and fine ash.

Sample 7-a contains 44 modal % orthopyroxene, 21% magnetite, 14% clinopyroxene, 8% cummingtonite, 3% epidote, 2% hornblende. Sample 7-b does 29% orthopyroxene, 20% epidote, 15% magnetite, 9% clinopyroxene, 9% cummingtonite and 4% hornblende.

Loc. 8 (Kamihagimori)

The outcrop at loc. 8 (Kamihagimori) includes, in ascending order, loess, 40 cm; unidentified ash, 6-7 cm; loess, 10 cm; Kth, 10 cm; loess, 10 cm; Kth, 10cm; unidentified ash, 5 cm; loess, 5 cm; Aso-4, 3 cm as patch; loess, 15 cm; Yk-Y, 20 cm; loess, over 80 cm. Dks is greenish gray ash layer (samples 8-a and 8-b). Dks is composed of coarse and fine ash.

Sample 8-a contains 51% magnetite, 29% orthopyroxene, 8% clinopyroxene, 4% epidote, 2% cummingtonite and 1% hornblende. Sample 8-b does 41% magnetite, 28% orthopyroxene, 9% clinopyroxene, 7% epidote, 6% cummingtonite and 2% hornblende.

3.2. Accessory minerals

Major minerals in Dks and Kth are magnetite, biotite, cummingtonite, pyroxenes, hornblende and epidote. A small amount of high-quartz is included in Dks and Kth. Accessory minerals which are classified as others in Fig. 2 are such as garnet, andalusite and allanite. These characteristic minerals are useful to estimate a source vent of Dks and Kth because they were derived from pelitic metamorphic rocks, skarns or some granites.

3.3. EPMA analyses of minerals

Major element chemistry of minerals was examined by EPMA (JEOL 8600S/M) at Faculty of Science, Yamagata University. Probe currents on the faraday cup are about 5×10^{-8} A. Counting times for elements are 10s (peak) and 5s (background). ZAF correction procedures are used.

3.3.1. Major element chemistry of cummingtonite, hornblende, orthopyroxene and clinopyroxene

Mg-values of cummingtonite, hornblende, orthopyroxene and clinopyroxene are shown in Fig. 3. Representative analyses of cummingtonite, hornblende, orthopyroxene and clinopyroxene are shown in Table 2.

Samples from loc. 1

Mg-value of cummingtonite ranges 0.583-0.592 and it is nearly constant variation. On the contrary, Mg-value of hornblende have wide variations as 0.504-0.521 in sample 1-o and 0.699-0.745 in sample 1-q. Mg-value of orthopyroxene also have wide variations as 0.607-0.746 in sample 1-j and 0.561-0.731 in sample 1-p.

Samples from locs. 2-8

Mg-value of cummingtonite ranges 0.581-0.593 and it is nearly constant. On the contrary, Mg-value of hornblende, orthopyroxene and clinopyroxene have wide variations such as 0.444-0.686, 0.361-0.671 and 0.583-0.845 respectively.

Most of amphibole is plotted in magnesio-hornblende field but some of them are

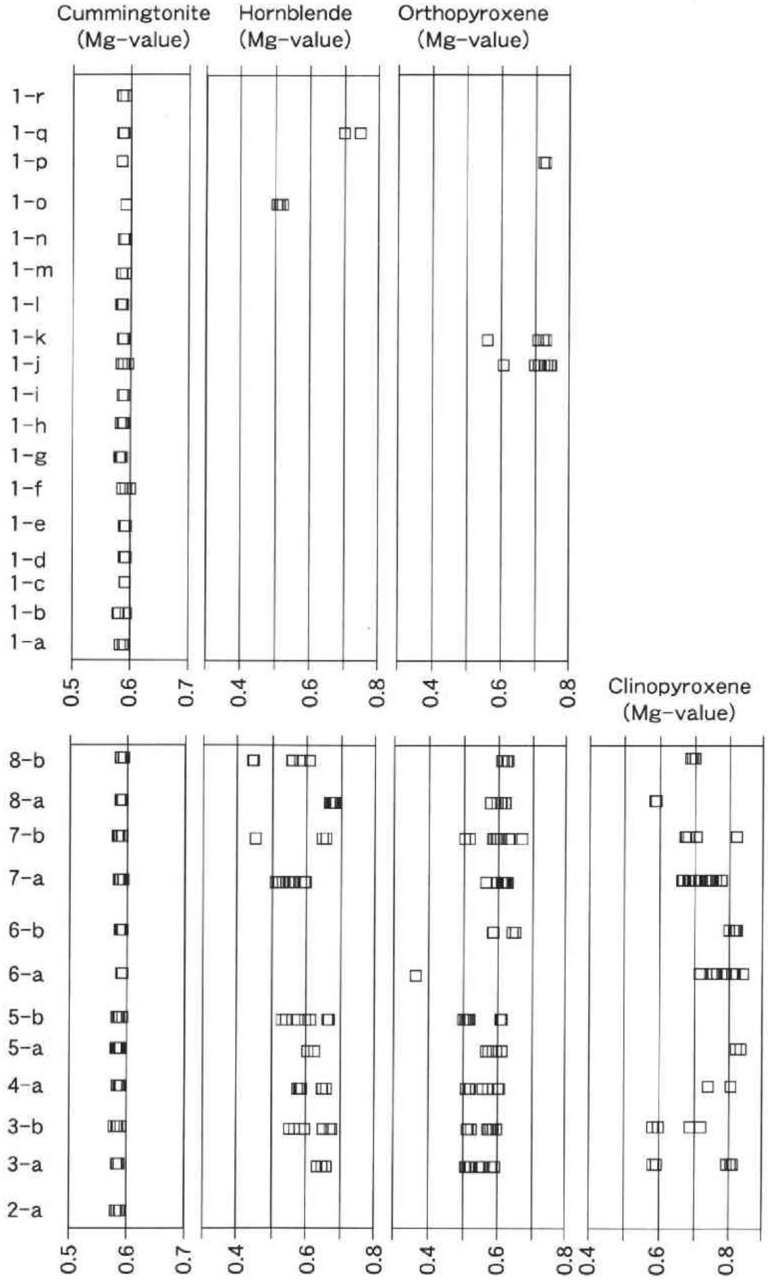

Fig. 3. Mg-value of minerals constituting Dks and Kth
Sampling points are shown in Fig. 2.

Table 2. Representative analyses of cummingtonite, hornblende (anhydrous basis of O=23), and orthopyroxene, clinopyroxene (O=6)

Mineral	Cummingtonite					Hornblende				Orthopyroxene				Clinopyroxene			
Tephra	Dks			Kth		Dks		Kth		Dks		Kth		Dks		Kth	
Point No.	1-a(1)	1-h(1)	1-j(1)	7-a(1)	7-b(1)	1-o(1)	1-q(1)	7-a(1)	7-b(1)	1-j(1)	1-p(1)	7-a(1)	7-b(1)	3-a(1)	3-b(1)	7-a(1)	7-b(1)
SiO_2	54.42	53.94	53.55	54.47	52.93	46.43	44.90	46.89	44.91	54.72	54.41	52.01	52.21	53.52	52.21	52.27	52.25
TiO_2	0.13	0.20	0.28	0.24	0.20	1.48	2.91	1.58	0.97	0.15	0.57	0.19	0.12	0.19	0.69	0.28	0.32
Al_2O_3	1.49	1.24	1.96	1.62	1.69	7.62	9.81	7.71	9.19	1.07	1.19	0.86	0.39	1.07	2.86	1.16	3.75
FeO	19.09	18.77	18.77	17.82	18.30	18.71	11.08	15.84	20.03	16.61	16.75	24.96	27.84	9.32	6.40	9.02	5.91
MnO	4.05	4.01	3.88	4.22	3.91	0.54	0.48	0.37	0.65	4.01	0.58	0.75	1.98	0.43	0.18	0.54	0.19
MgO	18.19	17.94	17.87	17.72	17.47	11.00	15.09	11.67	8.78	17.93	25.31	18.94	17.05	14.11	16.26	14.71	16.10
CaO	1.38	1.30	1.72	1.61	1.48	10.57	11.11	10.56	11.43	1.19	1.98	1.44	0.99	21.53	20.81	20.91	21.30
Na_2O	0.27	0.29	0.40	0.34	0.36	1.48	2.26	1.44	1.21	0.28	0.04	0.00	0.05	0.24	0.25	0.32	0.12
K_2O	0.01	0.01	0.00	0.00	0.01	0.34	0.75	0.56	0.89	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00
Total	99.03	97.70	98.43	98.04	96.35	98.17	98.39	96.62	98.06	95.97	100.83	99.15	100.64	100.41	99.66	99.22	99.94
	O=23									O=6							
Si	7.827	7.857	7.755	7.873	7.817	6.932	6.525	7.012	6.800	2.090	1.965	1.986	1.998	1.986	1.924	1.964	1.916
Ti	0.014	0.022	0.030	0.026	0.022	0.166	0.318	0.178	0.110	0.004	0.015	0.005	0.004	0.005	0.019	0.008	0.009
Al	0.253	0.213	0.334	0.276	0.293	1.341	1.680	1.358	1.640	0.048	0.051	0.019	0.009	0.047	0.124	0.026	0.081
Fe	2.296	2.287	2.273	2.154	2.260	2.336	1.347	1.981	2.537	0.530	0.506	0.797	0.891	0.289	0.197	0.283	0.181
Mn	0.494	0.495	0.476	0.517	0.490	0.068	0.059	0.046	0.083	0.130	0.018	0.024	0.064	0.014	0.006	0.017	0.006
Mg	3.900	3.896	3.858	3.819	3.847	2.449	3.270	2.601	1.983	1.021	1.362	1.078	0.973	0.781	0.893	0.824	0.880
Ca	0.212	0.202	0.267	0.250	0.234	1.691	1.729	1.692	1.854	0.049	0.077	0.059	0.041	0.856	0.822	0.842	0.837
Na	0.076	0.082	0.112	0.096	0.103	0.428	0.637	0.208	0.177	0.020	0.003	0.000	0.002	0.017	0.018	0.012	0.004
K	0.001	0.001	0.000	0.000	0.001	0.065	0.139	0.053	0.085	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
total	15.073	15.055	15.105	15.011	15.067	15.476	15.704	15.129	15.269	3.892	3.997	3.968	3.982	3.995	4.003	3.976	3.914
Mg-value	0.583	0.583	0.584	0.588	0.583	0.505	0.699	0.562	0.431	0.607	0.722	0.568	0.505	0.721	0.815	0.733	0.825

done in ferro-hornblende field of Leak's classification (Leak, 1978 ; Fig. 4).

3.3.2. Major element chemistry of garnet, andalusite and allanite

Major element chemistry of garnet is shown in Table 3. Sample g1-21 (points g1-21core and g1-21rim) from loc. 1 shows that spessartine components are rich (MnO=32.56-33.39). Sample g1-23 (points g1-23core and g1-23rim) from loc. 1 shows that andradite components are rich (Fe_2O_3=30.38-32.26, CaO=33.41-33.46). Sample g2-9 (points g2-9core and g2-9rim) from loc. 2 shows that grossular components are rich (Al_2O_3=23.53-24.10, CaO=22.31-23.75). Sample g2-27 (points g2-27core and g2-27rim) from loc. 2 shows that andradite components are rich (Fe_2O_3=30.82-31.77, CaO=33.73-33.86).

Major element chemistry of andalusite and allanite are shown in Table 4. Andalusite sample of an6-1 (point no. an6-1core and an6-1rim) is from loc. 6. Allanite samples of al1-11, al1-12, al1-29 are from loc.1 and samples al2-7, al2-8 are from loc. 2.

4. Discussion

4.1. Correlation of Dks and Kth

Dks and Kth are greenish gray coarse ash. Mineral assemblages of both tephra are magnetite, epidote[7)], biotite, cummingtonite, hornblende and pyroxenes in descend-

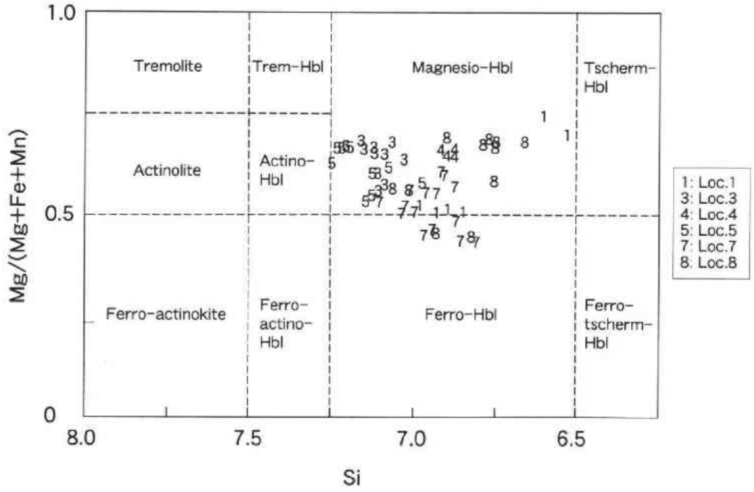

Fig. 4. Relationship between Si and Mg-value (Mg/Mg+Fe+Mn) of amphibole in Dks and Kth
Classification of hornblende is from Leak (1978).

Table 3. Chemical analyses of garnet (anhydrous basis of O=12)

Tephra	Dks							
Point No.	g1-21c	g1-21r	g1-23c	g1-23r	g2-9c	g2-9r	g2-27c	g2-27r
SiO_2	36.73	37.31	36.46	36.87	38.43	38.79	36.33	36.79
TiO_2	0.15	0.02	0.01	0.02	0.21	0.10	0.00	0.00
Al_2O_3	19.98	20.27	0.15	0.00	23.53	24.10	0.00	0.03
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	0.00	0.00	32.26	30.38	0.00	0.00	31.77	30.82
FeO	9.03	9.33	0.00	0.00	10.83	10.85	0.00	0.00
MnO	33.39	32.56	0.43	0.46	1.14	0.45	0.22	0.19
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.94	0.99	0.09	0.00	0.13	0.06	0.04	0.05
CaO	0.79	1.69	33.46	33.41	22.31	23.75	33.86	33.73
Total	101.01	102.17	102.86	101.14	96.58	98.10	102.22	101.61
					O=12			
Si	5.994	6.004	5.996	6.134	6.033	5.994	6.012	6.097
Ti	0.018	0.002	0.001	0.003	0.024	0.012	0.000	0.000
Al(IV)	0.006	0.000	0.004	0.000	0.000	0.006	0.000	0.000
Al(VI)	3.836	3.844	0.024	0.000	4.353	4.383	0.000	0.006
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe^{3+}	0.000	0.000	3.992	3.803	0.000	0.000	3.956	3.844
Fe^{2+}	1.232	1.256	0.000	0.000	1.422	1.401	0.000	0.000
Mn	4.615	4.438	0.059	0.065	0.152	0.058	0.031	0.027
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	0.228	0.238	0.021	0.000	0.030	0.013	0.011	0.012
Ca	0.138	0.291	5.895	5.956	3.752	3.932	6.002	5.991
Total	16.067	16.073	15.992	15.961	15.766	15.799	16.012	15.977

c: core, r: rim

Table 4. Chemical analyses of andalusite and allanite (anhydrous basis of O=13)

Mineral	Andalusite		Allanite					
Tephra	Kth		Dks					
Point No.	an6-1c	an6-1r	al1-11	al1-12	al1 29	al1 30	al2 7	al2 8
SiO_2	36.25	35.90	30.36	30.51	30.43	30.74	30.31	30.48
TiO_2	0.05	0.13	1.28	1.28	1.43	1.49	1.36	1.41
Al_2O_3	59.81	62.01	14.37	14.39	13.80	13.94	14.25	14.05
FeO	1.59	1.15	12.49	13.54	13.68	14.10	14.01	12.72
MnO	0.02	0.00	0.15	0.34	0.20	0.23	0.26	0.41
MgO	0.01	0.00	0.75	0.77	0.80	0.81	0.75	0.70
CaO	0.02	0.00	11.64	11.83	11.01	11.64	11.33	11.89
Na_2O	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03
K_2O	0.00	0.02	0.02	0.02	0.00	0.00	0.00	0.02
Total	97.75	99.21	71.07	72.67	71.36	72.97	72.27	71.71
				O=13				
Si	2.622	2.556	3.517	3.484	3.532	3.504	3.485	3.515
Ti	0.003	0.007	0.112	0.110	0.125	0.128	0.117	0.122
Al	2.550	2.602	1.962	1.937	1.888	1.873	1.931	1.909
Fe	0.096	0.068	1.210	1.293	1.327	1.344	1.347	1.227
Mn	0.001	0.000	0.014	0.033	0.020	0.022	0.026	0.040
Mg	0.001	0.000	0.130	0.130	0.138	0.138	0.129	0.121
Ca	0.001	0.000	1.445	1.447	1.369	1.422	1.396	1.469
Na	0.000	0.000	0.001	0.000	0.002	0.005	0.000	0.006
K	0.000	0.001	0.002	0.003	0.000	0.000	0.000	0.003
total	5.274	5.234	8.392	8.438	8.401	8.436	8.431	8.412
Mg-value	0.012	0.005	0.096	0.090	0.093	0.092	0.086	0.087

c: core, r: rim

ing order.

Cummingtonite which is a major mineral in Dks and Kth shows nearly constant variation in Mg-value (Fig. 3). This similarity of cummingtonite chemistry indicates Dks and Kth correlate each other.

Pyroxenes and hornblende show vertical variation in modal abundance. Mg-value of these minerals range widely and it implies contamination of accidental or accessory materials.

4.2. Eruptive process of Dks and Kth

Mineral assemblage is similar between Dks and Kth but the modal abundances vary vertically (Fig. 2). Dks at the western side of the Ou Ranges (locs. 1, 2) comprises cummingtonite, biotite, high-quartz and epidote as a whole layer. The upper

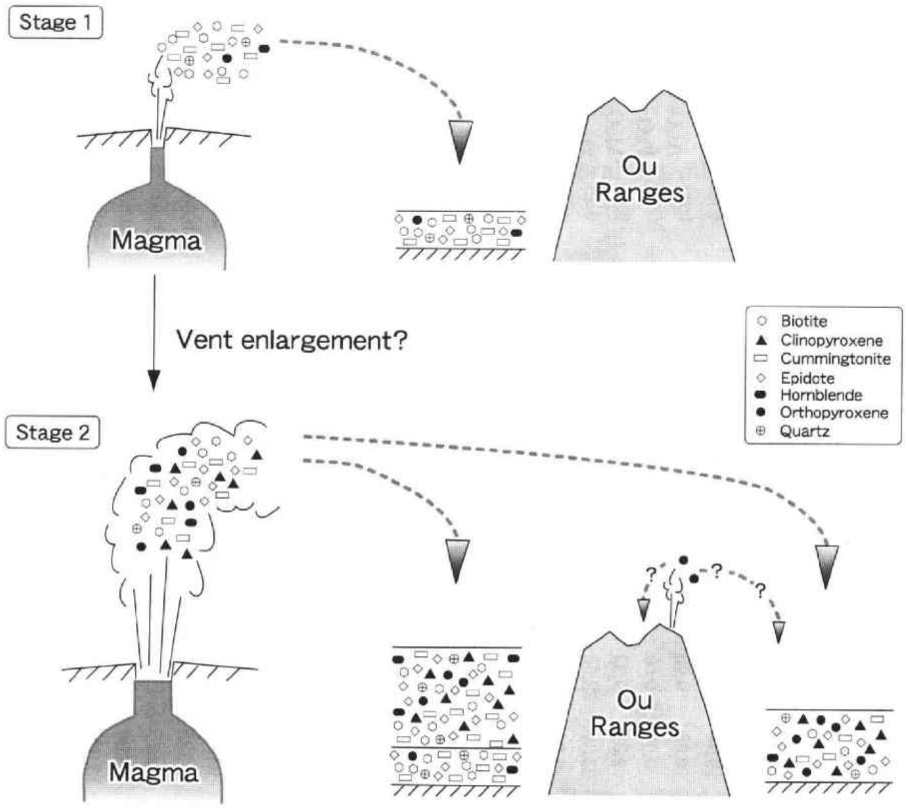

Fig. 5 Eruptive process of Dks (Kth) estimated from variations of mineral assemblage of Dks (Kth)
Magnetite and others are not shown.

part of Dks also contains orthopyroxene, clinopyroxene and hornblende.

On the contrary, Dks at the inside of the Ou Ranges (locs. 3, 4) and Kth at the eastern side of the Ranges include cummingtonite, biotite, high-quartz, epidote, hornblende and pyroxenes as a whole layer. These indicate that the upper part of Dks spread over the central part of Northeast Japan.

The lower part of Dks is interstratified coarse ash and fine ash layers and the facies is observed only at Dokusawa and its southwest. This indicates that the lower part of Dks is intermittent small-scale eruption.

Eruptive process of Dks (Kth) derived from facies change and mineral assemblage is estimated as follows (Fig. 5).

Stage 1 : Interstratified coarse ash and fine ash layers deposited at intermittent small-scale eruption of Dks. These ash layers include a lot of hydrous mineral such as biotite and cummingtonite. The magma chamber might be fractionated and the upper part of magma (hydrous) erupted at this stage.

Stage 2 : After vent enlargement, huge eruption occurred at this stage. A lot of accidental or accessory materials contaminated the magma because epidote increase at the upper part of Dks in modal abundance. The upper part of Dks includes not only biotite and cummingtonite but also pyroxenes and hornblende. This shows that the upper part of magma (hydrous) and the lower part of magma (anhydrous) erupted at the same time. We redefine Dks and Kth as Dokusawa tephra (Dks).

4.3. A source vent of Dks

Isopach of Dks shows that a source vent of Dks is presumably situated in the area of Hijiori caldera-Mt. Gassan-Mt. Hayama triangle or its southwest (Fig. 1).

Dks includes epidote, garnet, andalusite and allanite characteristically. These minerals are not originated from the Dks magma but from rocks around magma chamber.

Estimated source vent of Dks is situated at the northern elongation of Abukuma Belt (Kuroda, 1963 ; Oide *et al.*, 1989) which is bounded by Tanakura and Hatagawa tectonic lines. Abukuma belt includes Gosaisho-Takanuki metamorphic rocks and Takine Group with granitic rocks. Gosaisho-Takanuki metamorphic rocks are intervened by limestone which includes skarn minerals such as epidote and grandite garnet (andradite and grossular). Limestone in Takine Group also contains skarn minerals such as andalusite and grossular. Granitic rocks contains small amounts of allanite. These show that minerals such as epidote, garnet, andalusite and allanite are originated from skarn, mudstone, granite or manganic ore in Abukuma Belt.

5. Conclusion

Dokusawa tephra (Dks) is distributed on the western sides of the Ou Ranges and Kitahara tephra (Kth) is on the eastern side of the Ranges. Both tephra are Late Pleistocene tephra layers containing biotite and cummingtonite characteristically. We examined modal abundance and chemistry of minerals and discussed correlation of the tephra layers. Conclusion is as follows.

(1) Dks and Kth correlate with each other because chemical composition of cummingtonite are quite similar. We redefine the tephra layers as Dokusawa tephra (Dks). Type locality of Dks is Dokusawa. A source vent of Dks is presumably situated in the area of Hijiori caldera-Mt. Gassan-Mt. Hayama triangle or its southwest.

(2) Cummingtonite chemistry is a key to correlate Dks because cummingtonite shows nearly constant variation in Mg-values. On the contrary, Mg-values of hornblende, orthopyroxene and clinopyroxene have wide variations.

(3) Dks contains cummingtonite, biotite, high-quartz and epidote as a whole layer. The upper part of Dks also includes orthopyroxene, clinopyroxene and hornblende. The modal abundance of Dks at the eastern part of the Ou Ranges resembles the upper part of Dks. These facts indicate that the upper part of Dks is distributed on both sides of the Ou Ranges.

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Notes

1) This paper reports newly analyzed data which are not shown in Matsu'ura *et al.* (2002).
2) Mg-value was calculated by authors.
3) Ages of marine isotope stratigraphy include 6,200–7,080 yrs errors between 84 and 95 ka (Martinson *et al.*, 1987).
4) Biotite is not discussed quantitatively in modal abundance because biotite is flow away at the separation.
5) Clay layer includes Dks material such as cummingtonite, biotite, etc. This layer is not determined as secondary Dks or magmatophreatic explosion sediments.
6) Silt layer may be secondary deposits of SK.

7) Epidote is derived from principally from basement.

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